PWG5 (Heavy Flavour) summary

Alexander Zinchenko

Outline

1. The mission statement
2. Charm production cross-section
3. Scope of activities
4. Inner Tracking System (ITS) studies
5. Related Work Packages:
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    2. Exclusive D-meson decay selection
6. D-meson semileptonic decays
7. J/ψ → e+e- selection
8. Particle ID
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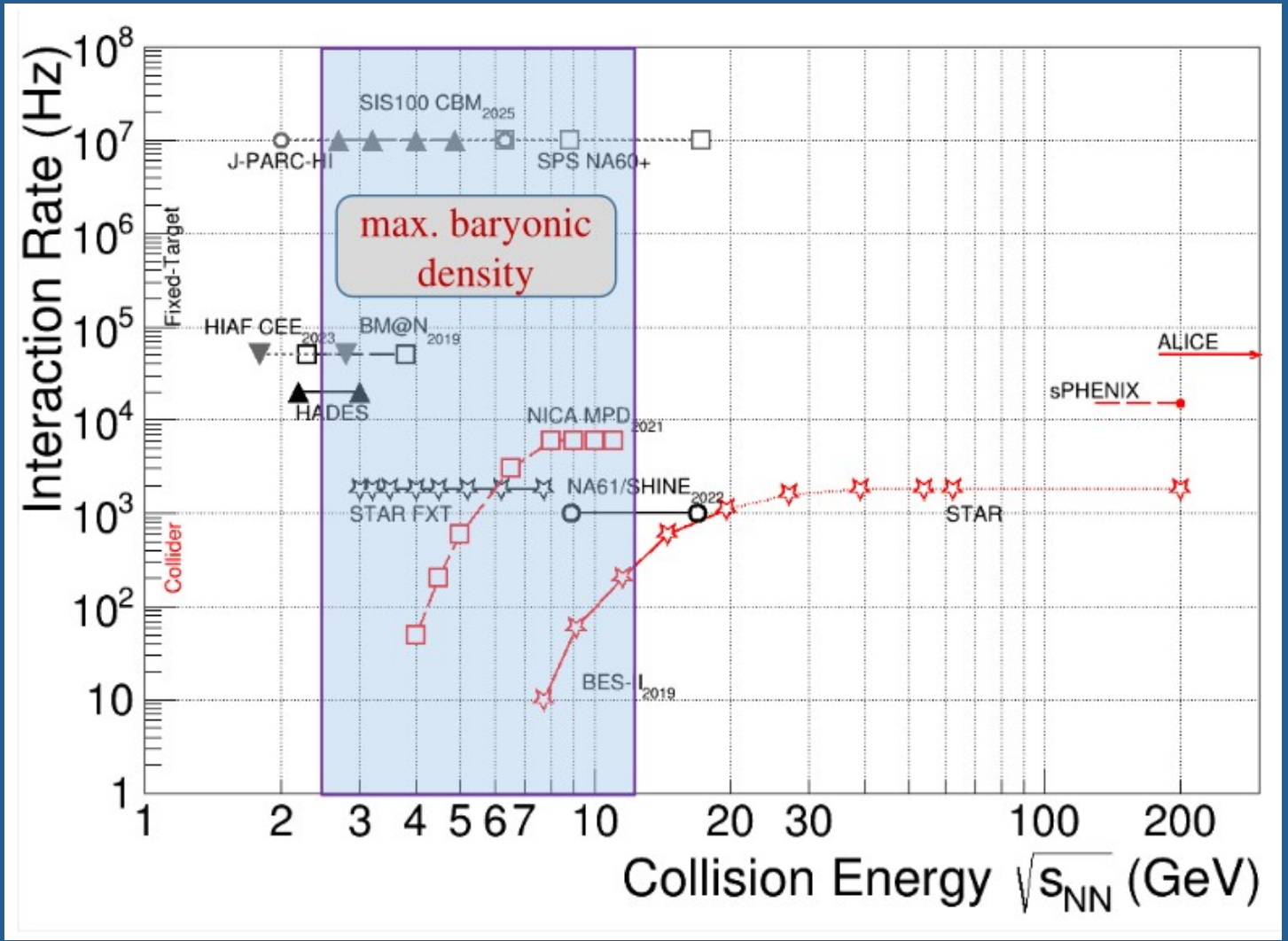
The heavy-flavour mission statement

One of the important issues related to relativistic heavy-ion collisions is the mechanism of heavy-flavour (charm and beauty) production. So far, b-hadrons are only accessible at LHC. Charmed hadrons are also visible at RHIC and SPS.

Studying the charmonium yield relative to the total charm yield (via open charm measurements) would allow disentangling initial and final state effects, revealing the properties of hidden and open charm transport through the dense medium created in nucleus-nucleus collisions.

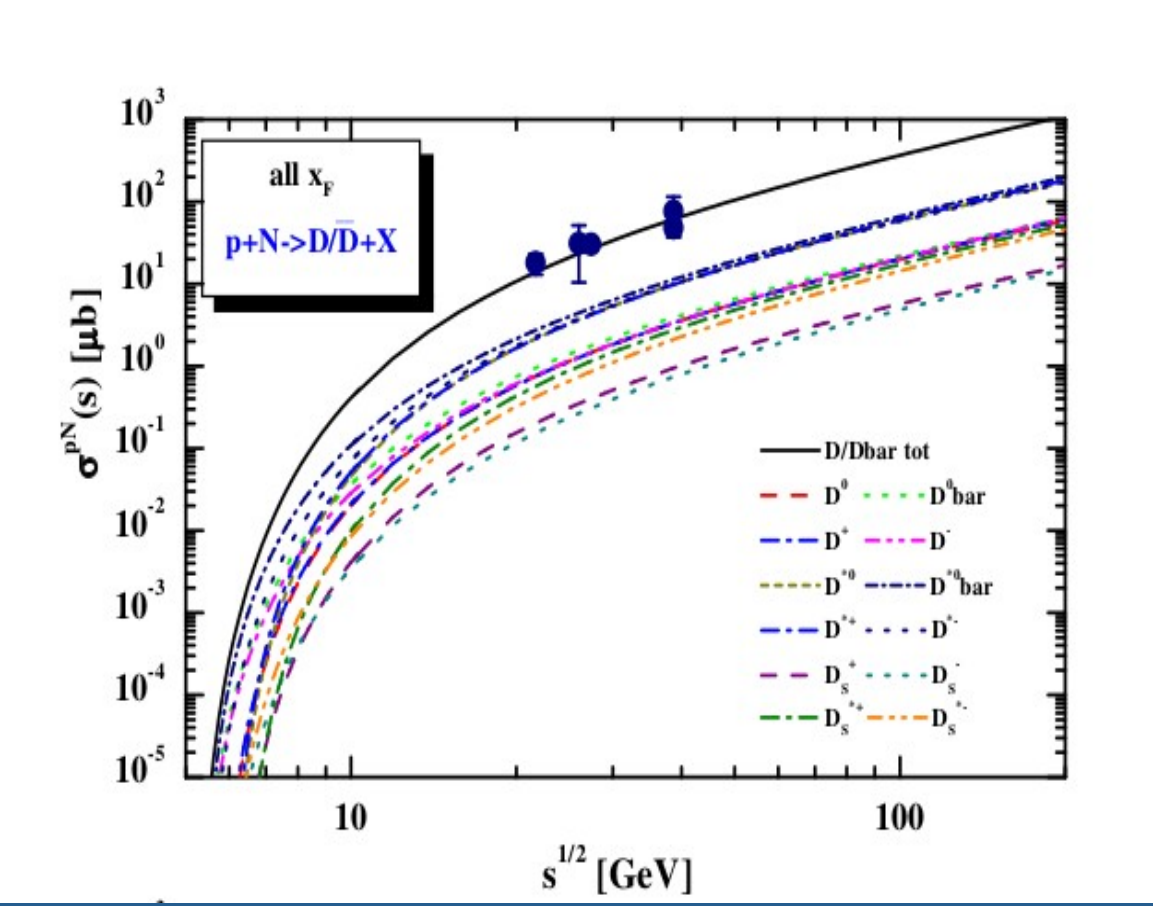
Landscape of heavy-ion experiments

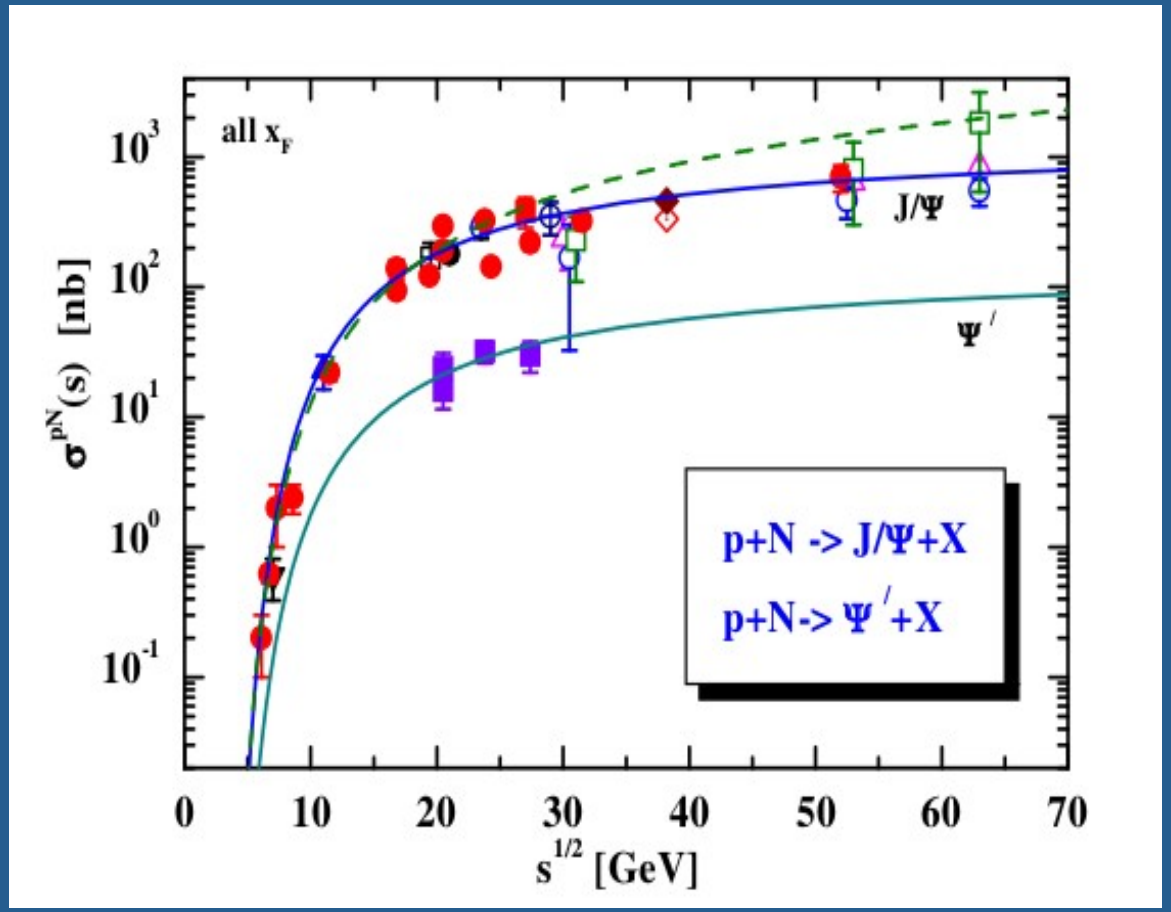


- At present, MPD/NICA, NA61/SHINE at SPS and CBM/SIS100 have charm studies in their physics programs.

Hadron	Decay channel	$c\tau$ [μm]	BR
D^0	$\pi^+ + K^-$	123	3.89%
D^+	$\pi^+ + \pi^+ K^-$	312	9.22%
D_s^+	$\pi^+ + K^- + K^+$	150	5.50%
Λ_c	$p + \pi^+ + K^-$	60	5.00%
J/ψ	$e^- + e^+$		6.00%

Charm production cross-sections





- W. Cassing, E. L. Bratkovskaya, A. Sibirtsev, “Open charm production in relativistic nucleus-nucleus collisions”, arXiv:nucl-th/0010071, 2001

Charm production cross-sections

√s = 7 GeV

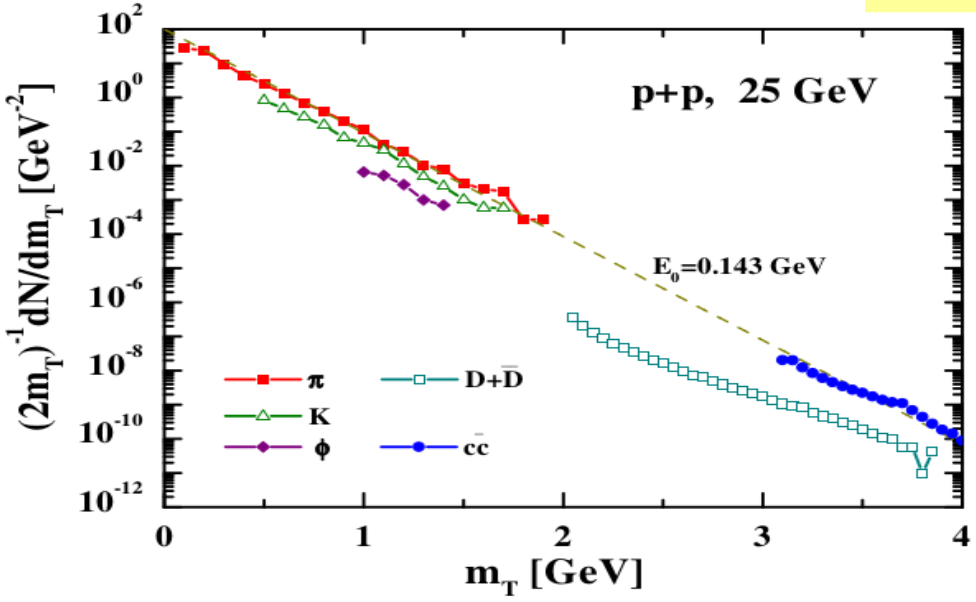


FIG. 5. The transverse mass specta from pp collisions at $T_{lab} = 25$ GeV for pions (full squares), kaons (open triangles), and ϕ-mesons (full rhombes) from the LUND string model [52] as implemented in HSD. The $D + \bar{D}$ meson (open squares) and charmonium (full dots) spectra – including the decay $\chi_c \to J/\Psi + \gamma$ – result from the parametrizations specified in Section 2. The dashed line shows an exponential with slope parameter $E_0 = 0.143$ GeV.

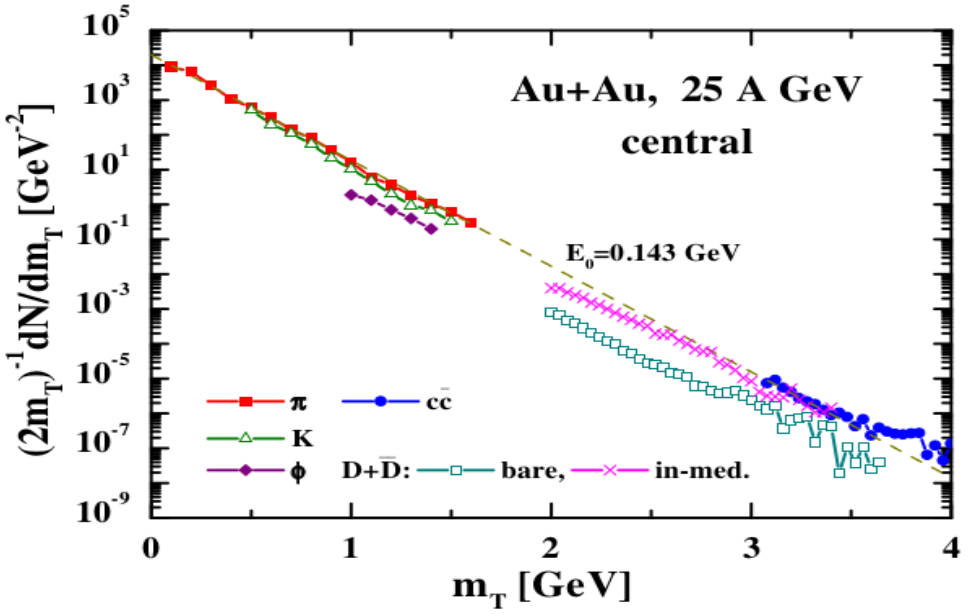


FIG. 16. The transverse mass spectra of pions (full squares), kaons (open triangles), ϕ-mesons (full rhombes), $D + \bar{D}$ mesons (open squares) and $J/\Psi, \Psi'$ mesons (full dots) in the HSD approach for a central $Au + Au$ collision at 25 A·GeV without including self energies for the mesons. The crosses stand for the D-meson m_T spectra when including an attractive mass shift according to (9). The thin dashed line shows an exponential with slope parameter $E_0 = 0.143$ GeV. Note that final state elastic scattering of kaons and ϕ-mesons with pions has been discarded in the calculations.

- W. Cassing, E. L. Bratkovskaya, A. Sibirtsev, “Open charm production in relativistic nucleus-nucleus collisions”, arXiv:nucl-th/0010071, 2001

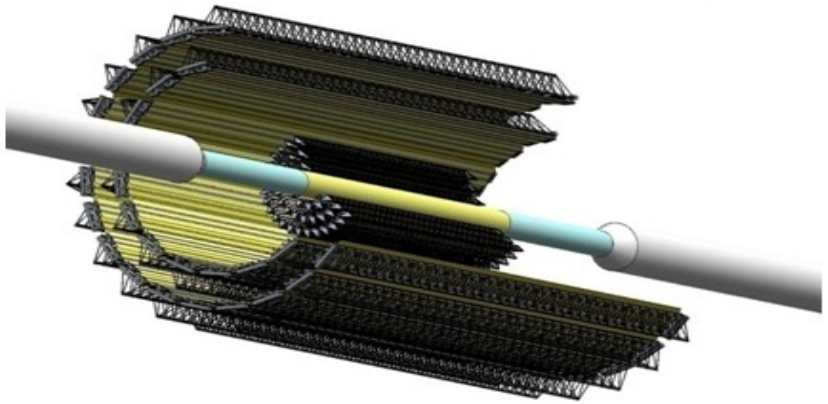
Scope of activities

1. Open charm studies: exclusive decays → Inner Tracking System (ITS) performance evaluation (synergy with ITS project) → dedicated track reconstruction methods (“Vector Finder”)
2. Semi-leptonic decays and charmonia → lepton (electron) tagging (synergy with dilepton studies)

MPD Inner Tracking System based on MAPS

Reconstruction of charmed particles in Au+Au central collisions with MPD ITS3+TPC tracking system

Kondratev V., Murin Yu.



MPD WPG5

MPD Inner Tracking System based on MAPS

MPD ITS geometric models

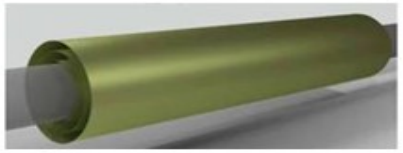
Two ITS geometric models were used for simulation:

1) project model (ITS-5-40) with 5 layers consisting of ladders with standard MAPS

Sensitive area: 15×30 mm²
Thickness: 50 µm
Number of pixels: 512×1024
Pixel size: 28×28 µm².

2) ITS3-like model (ITS-5-35) with OB consisting of 2 layers of standard MAPS and IB consisting of 3 layers of bended staves of MAPS (15 um pitch) with large area and thickness of 30 µm

Size of bended MAPS:
1 layer – 280*56.5 mm²
2 layer – 280*75.5 mm²
3 layer – 280*94.0 mm²



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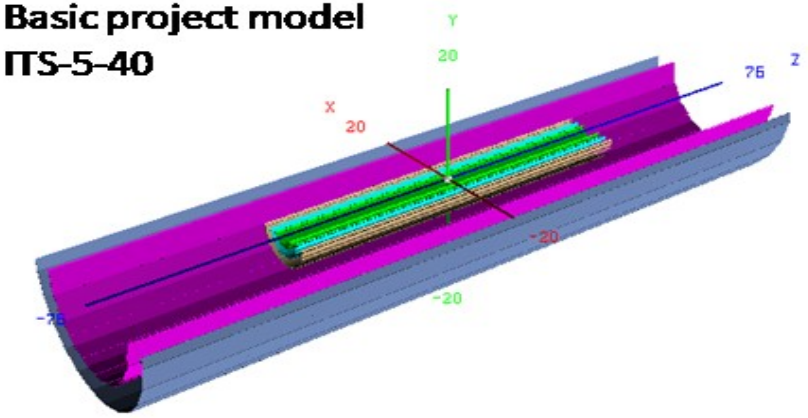
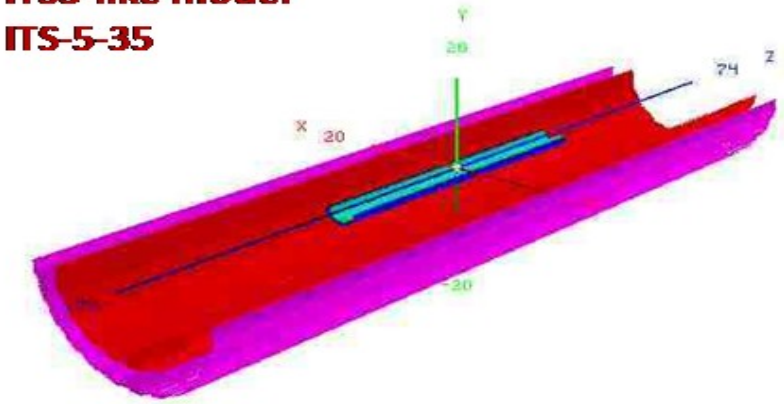
MPD Inner Tracking System based on MAPS

MPD ITS geometric models

Basic project model
ITS-5-40



ITS3-like model
ITS-5-35



Layer	No of MAPS	R_{min}, mm	R_{max}, mm	Length, mm
1	24 *12	22.4	26.7	750
2	24*22	40.7	45.9	750
3	24*32	59.8	65.1	750
4	98*36	144.5	147.9	1526
5	98*48	194.4	197.6	1526

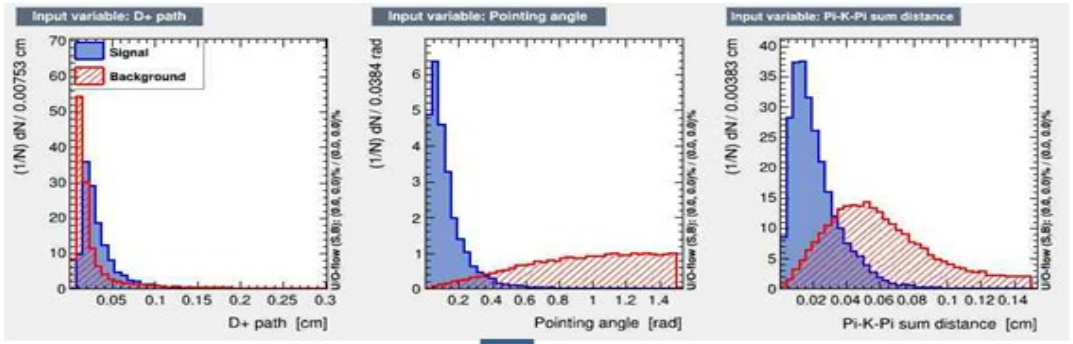
Layer	No of MAPS	R_{min}, mm	R_{max}, mm	Length, mm
1	4	18	18.03	560
2	4	24	24.03	560
3	4	30	30.03	560
4	98*36	144.5	147.9	1526
5	98*48	194.4	197.6	1526

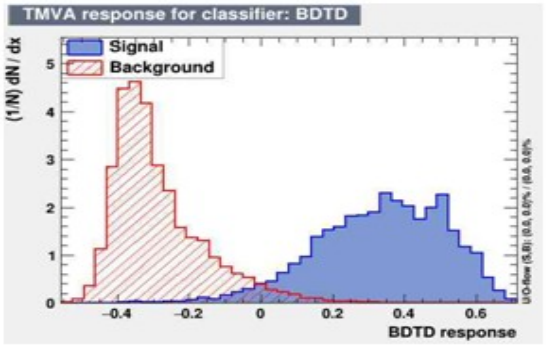
3

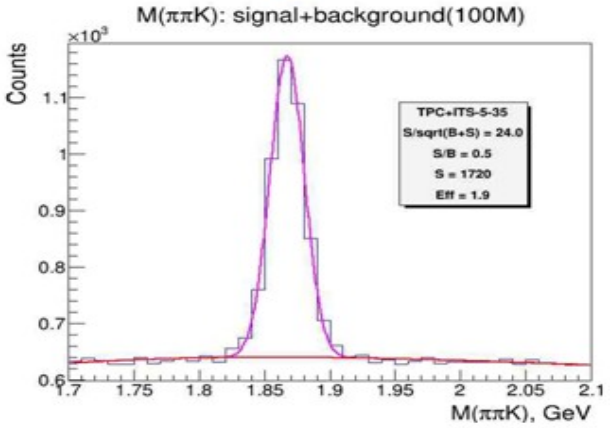
MPD Inner Tracking System based on MAPS

D^+ reconstruction in ITS-5-35 + TPC using VF + TMVA

dca(π), dca(K), dist(πK), λ(D^+), θ(D^+) cuts → BDT cut





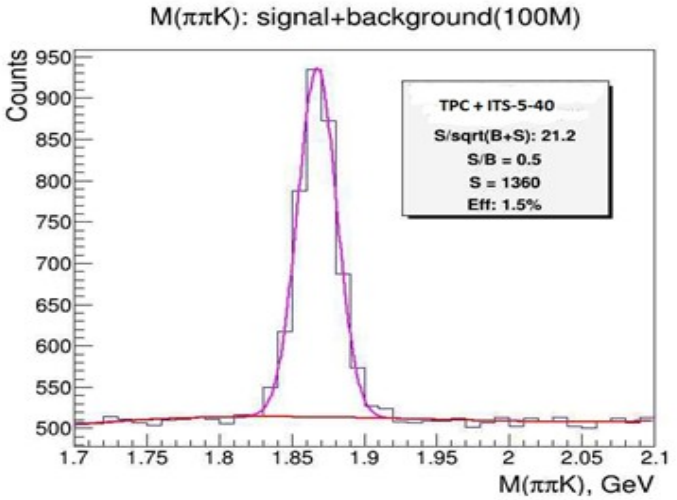


D^+ reconstruction efficiency obtained: ε=1.9%

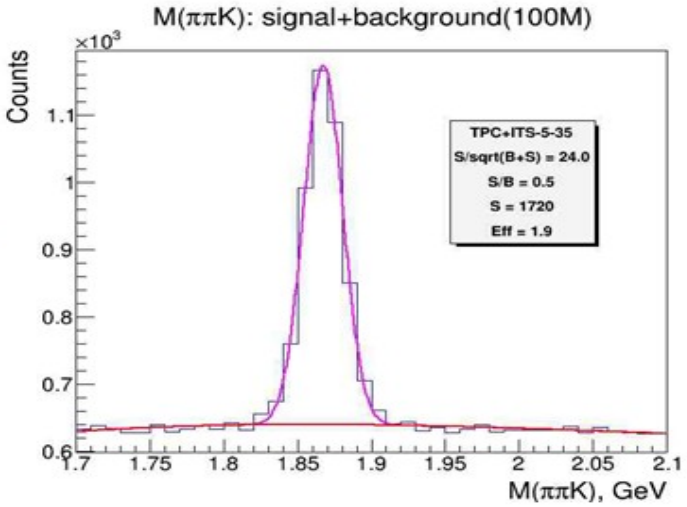
MPD Inner Tracking System based on MAPS

D^+ reconstruction efficiency with two ITS models

Project model



ITS3-like model



ITS	S	S/B	$S/\sqrt{S+B}$	ε, %
ITS-5-40	1360	0.50	21.2	1.5
ITS-5-35	1720	0.50	24.0	1.9

The reconstruction efficiency increases by 25% when using ITS with an Internal Barrel built on the base of a new type of sensors (bended MAPS with large area)

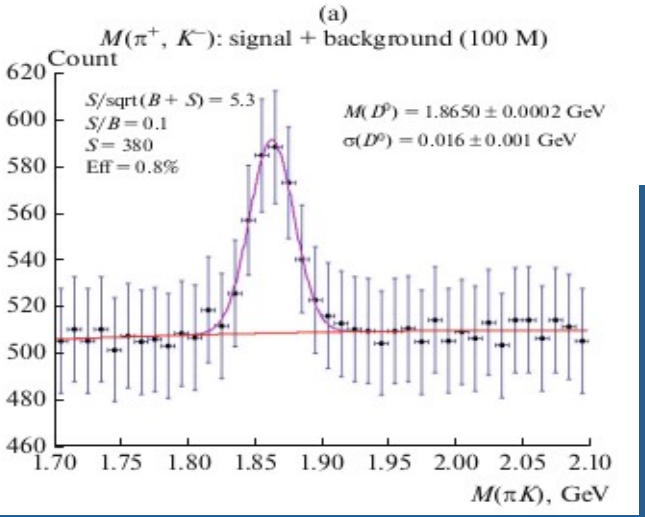
5

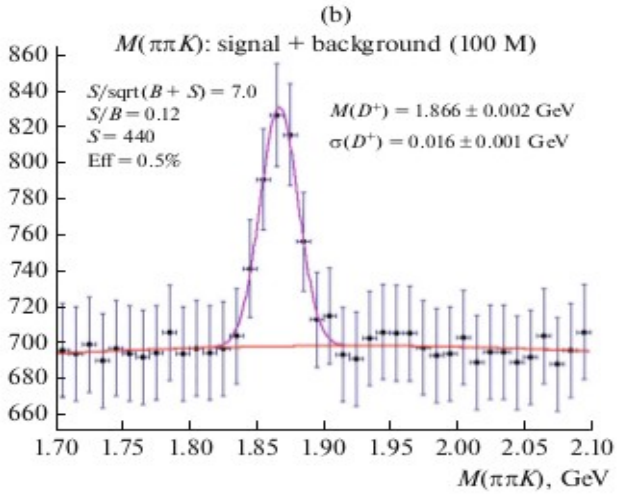
MPD Inner Tracking System based on MAPS

Published articles

1. V. P. Kondratyev, N. A. Maltsev and Yu. A. Murin.
Identification Capability of the Inner Tracking System for Detecting D Mesons at the NICA-MPD Facility.
Bulletin of the Russian Academy of Sciences: Physics, **2022**, Vol. 86, No. 8, pp. 1005–1009.

2. Zherebchevsky, V. I., Maltsev, N. A., Nesterov, D. G., Belokurova, S. N., Vechernin, V. V., Igolkin, S. N., Kondratiev, V. P., Lazareva, T. V., Prokofiev, N. A., Rakhmatullina, A. R. & Feofilov, G. A.
New Technologies for the Vertex Detectors in the NICA Collider Experiments.
Bulletin of the Russian Academy of Sciences: Physics. **2022**, Vol.86,No. 8, pp. 948-955.





RSF Grant for SpbU

Leader: Vladimir Zherebchevsky

Superdense nuclear matter and methods of its study in experiments at the NICA accelerator-storage complex

2023-2025

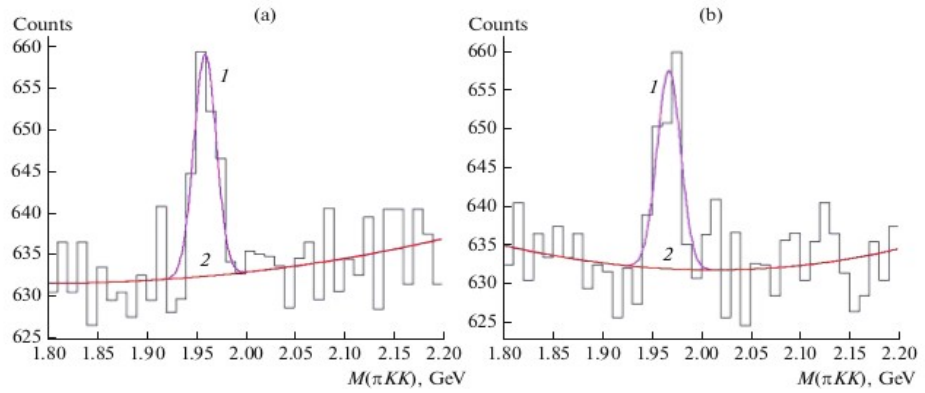
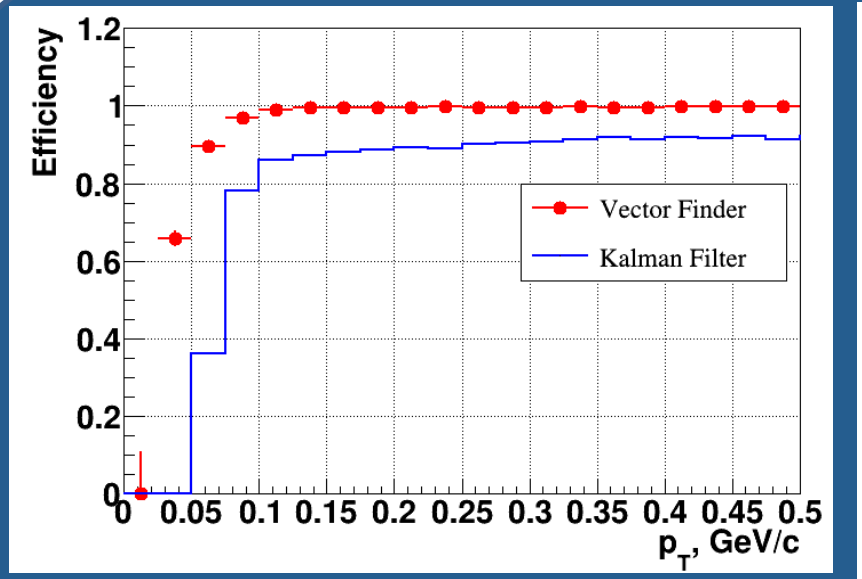
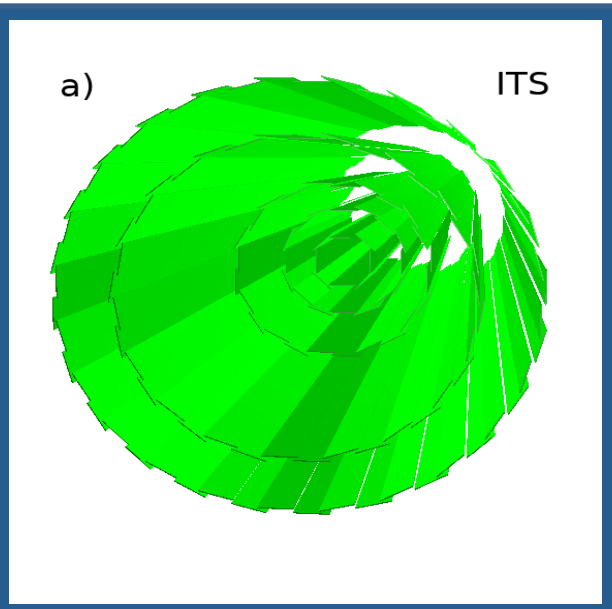
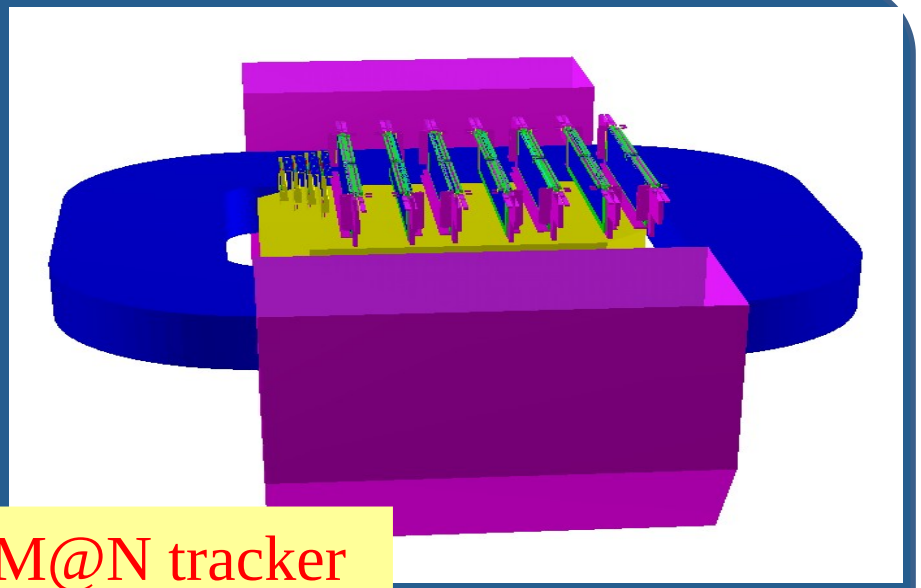


Fig. 3. Signal of D_s^+ mesons in the invariant-mass spectrum, separated according to (a) TC and (b) MVA in 10^8 central Au + Au collisions at $\sqrt{s_{NN}} = 9$ GeV: (*1*) full spectrum, (*2*) residual combinatorial background.

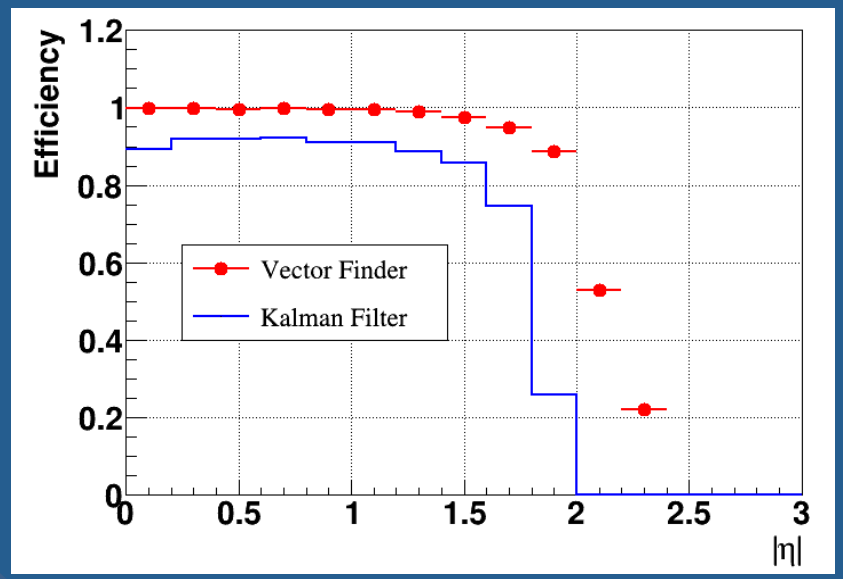
Track reconstruction: Vector Finder for ITS

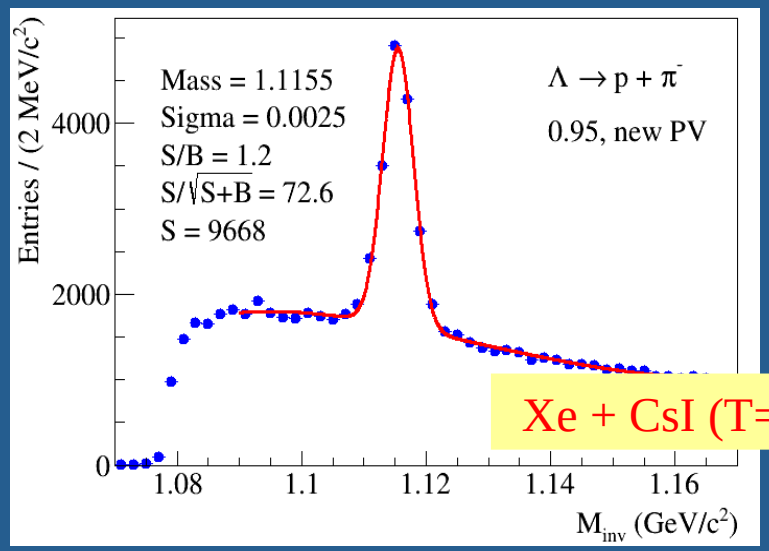


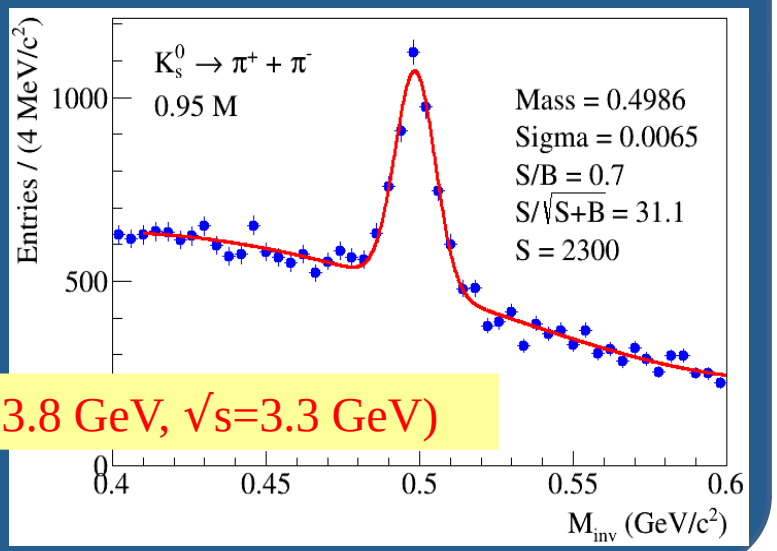




BM@N tracker



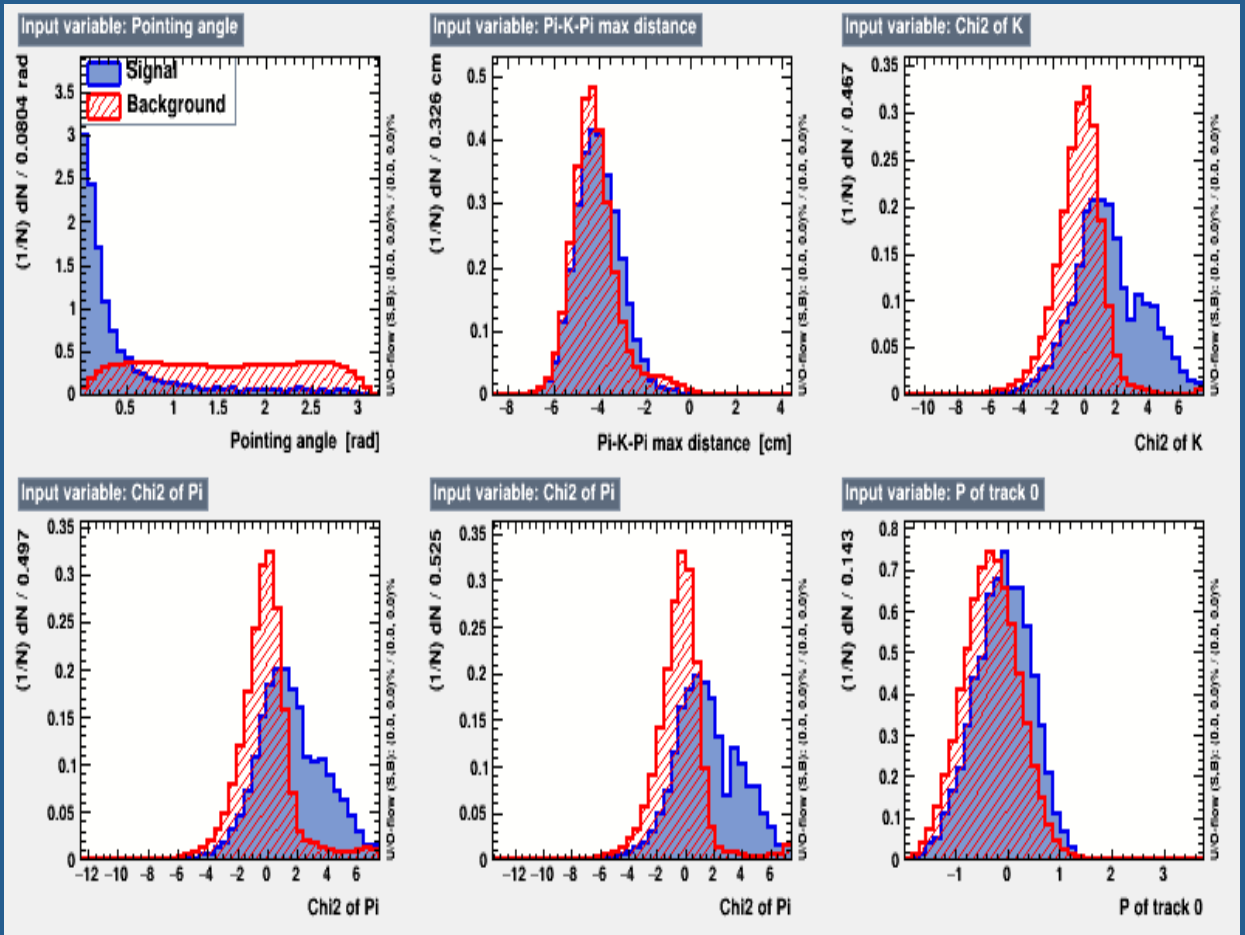


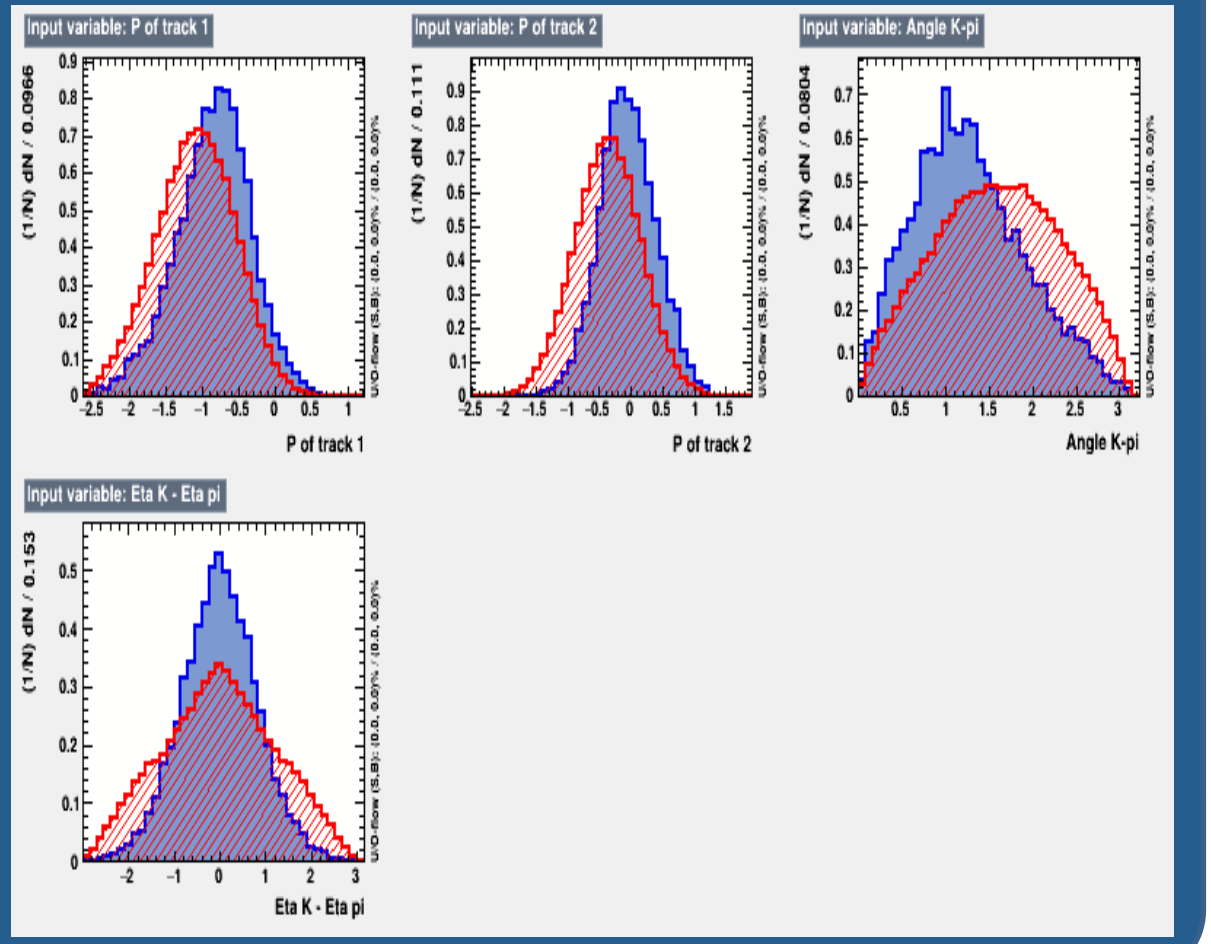


Xe + CsI (T=3.8 GeV, √s=3.3 GeV)

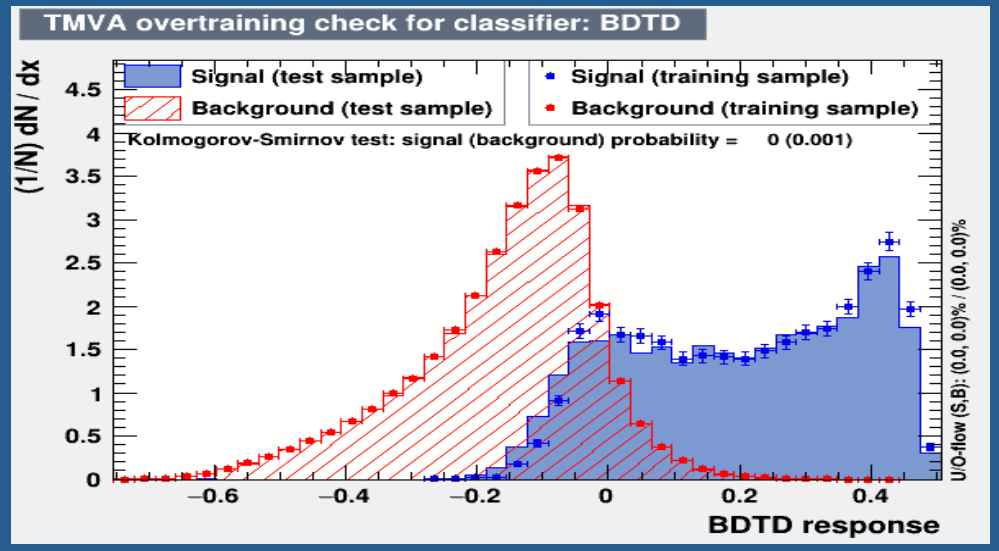
TMVA package: input variables

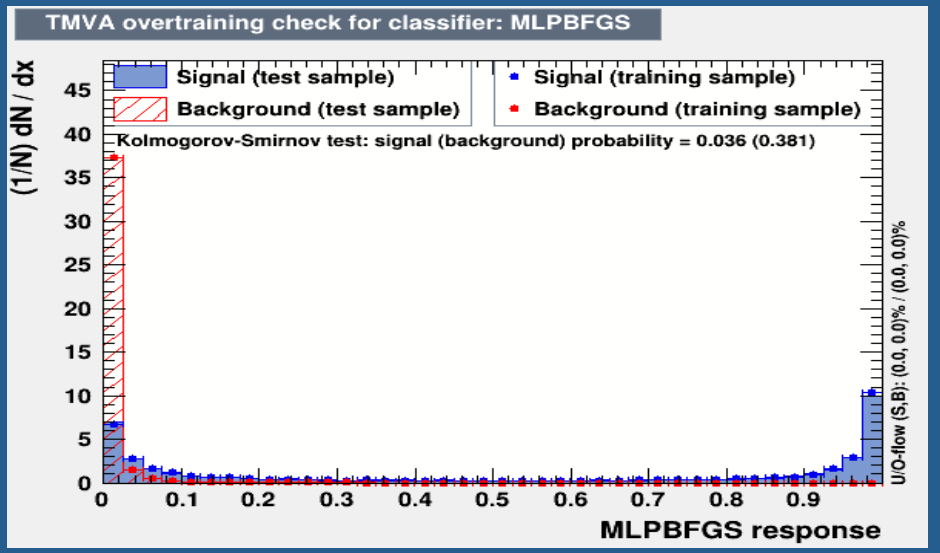
p+p @ 25 GeV Pythia8 (Equivalent statistics ~1B events)
Thanks to V.Kondratev for sharing his experience with TMVA package usage

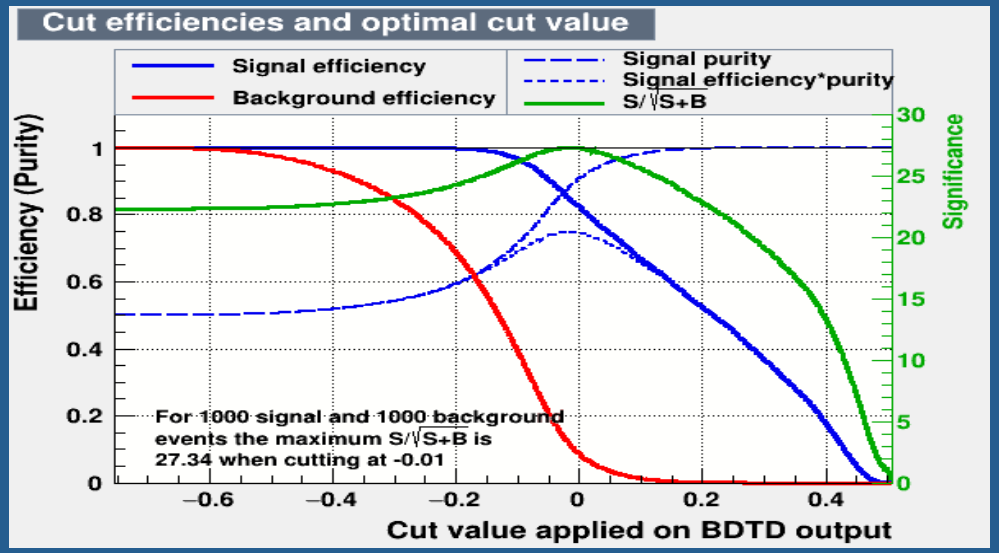


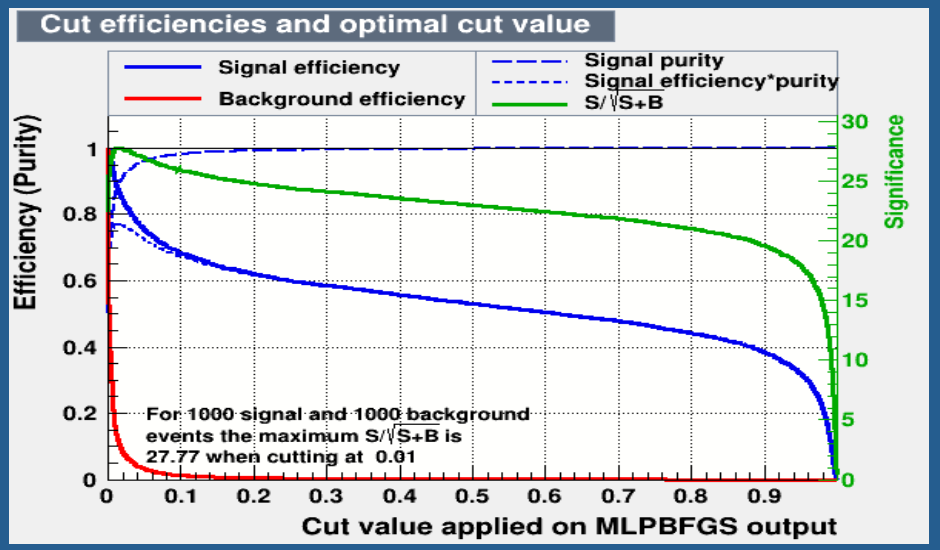


TMVA package: network performance



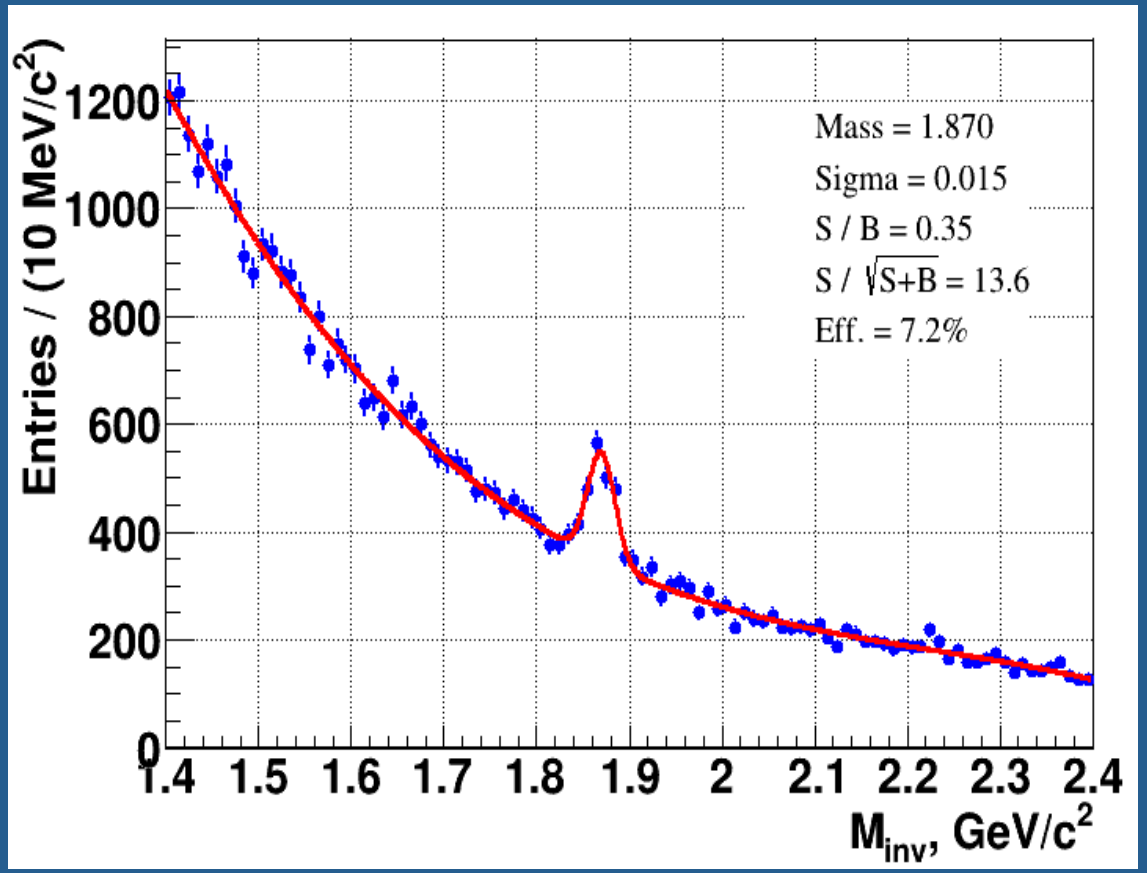




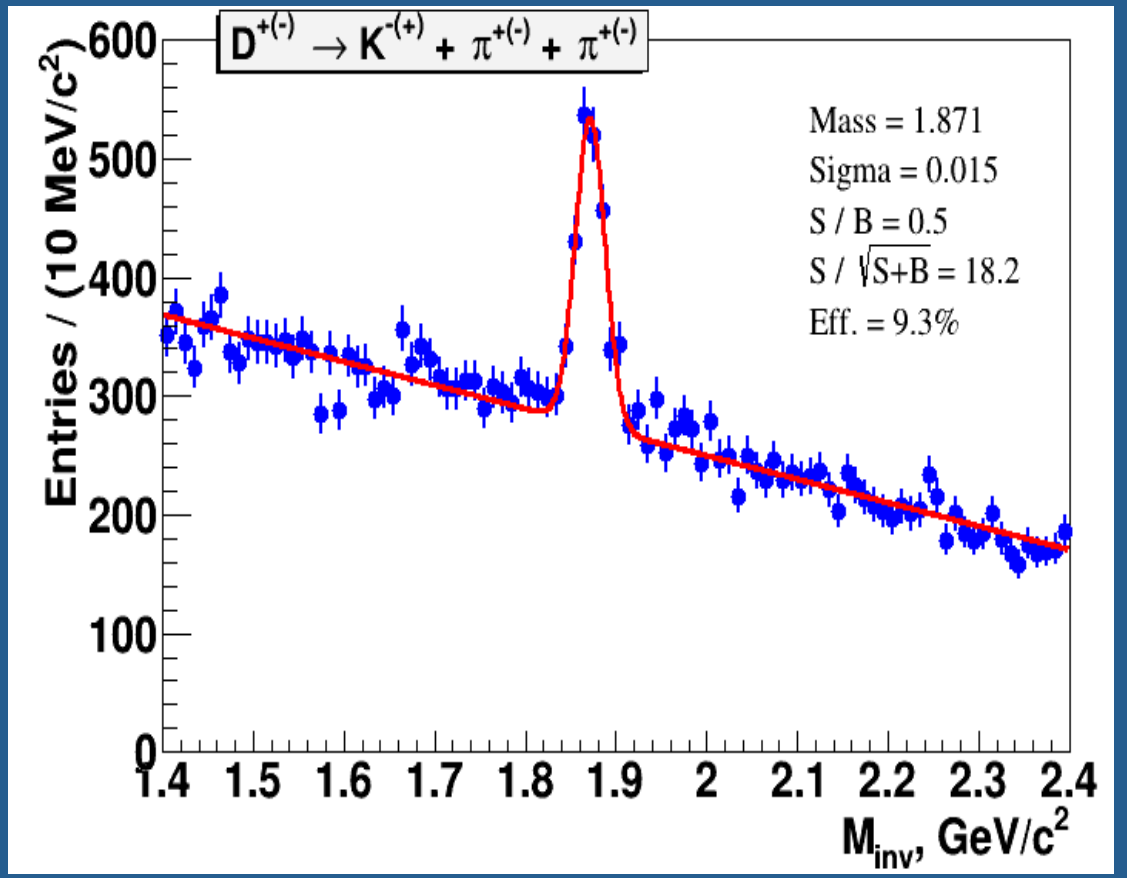


$D^{+(-)}$ 3-prong decays

Cuts on variables



TMVA



Semileptonic decays: inclusive electrons (83+% of ECAL modules will be ready)

D^+ DECAY MODES

Most decay modes (other than the semileptonic modes) that involve a neutral K meson are now given as K^0_S modes, not as $\overline{K}^0$ modes. Nearly always it is a K^0_S that is measured, and interference between Cabibbo-allowed and doubly Cabibbo-suppressed modes can invalidate the assumption that $2\,\Gamma(K^0_S) = \Gamma(\overline{K}^0)$.

	Mode	Fraction (Γ_i/Γ)	Scale factor/ Confidence level
	Inclusive modes		
Γ_1	e^+ semileptonic	(16.07 ± 0.30) %	
Γ_2	μ^+ anything	(17.6 ± 3.2) %	
Γ_3	K^- anything	(25.7 ± 1.4) %	
Γ_4	$\overline{K}^0$ anything + K^0 anything	(61 ± 5) %	
Γ_5	K^+ anything	(5.9 ± 0.8) %	
Γ_6	$K^*(892)^-$ anything	(6 ± 5) %	
Γ_7	$\overline{K}^*(892)^0$ anything	(23 ± 5) %	
Γ_8	$K^*(892)^0$ anything	< 6.6 %	CL=90%
Γ_9	η anything	(6.3 ± 0.7) %	
Γ_{10}	η' anything	(1.04 ± 0.18) %	
Γ_{11}	ϕ anything	(1.12 ± 0.04) %	

D^0 DECAY MODES

Most decay modes (other than the semileptonic modes) that involve a neutral K meson are now given as K^0_S modes, not as $\overline{K}^0$ modes. Nearly always it is a K^0_S that is measured, and interference between Cabibbo-allowed and doubly Cabibbo-suppressed modes can invalidate the assumption that $2\,\Gamma(K^0_S) = \Gamma(\overline{K}^0)$.

	Mode		Fraction (Γ_i/Γ)	Scale factor/ Confidence level
	Topological modes			
Γ_1	0-prongs	[a]	(15 ± 6) %	
Γ_2	2-prongs		(71 ± 6) %	
Γ_3	4-prongs	[b]	(14.6 ± 0.5) %	
Γ_4	6-prongs	[c]	(6.5 ± 1.3) $\times 10^{-4}$	
	Inclusive modes			
Γ_5	e^+ anything	[d]	(6.49 ± 0.11) %	
Γ_6	μ^+ anything		(6.8 ± 0.6) %	
Γ_7	K^- anything		(54.7 ± 2.8) %	S=1.3
Γ_8	$\overline{K}^0$ anything + K^0 anything		(47 ± 4) %	
Γ_9	K^+ anything		(3.4 ± 0.4) %	
Γ_{10}	$K^*(892)^-$ anything		(15 ± 9) %	

Transverse momentum and centrality dependence of high-p_T non-photonic electron suppression in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV

B.I. Abelev,[9] M.M. Aggarwal,[30] Z. Ahammed,[45] B.D. Anderson,[20] D. Arkhipkin,[13] G.S. Averichev,[12] Y. Bai,[28] J. Balewski,[17] O. Barannikova,[9] L.S. Barnby,[2] J. Baudot,[18] S. Baumgart,[50] V.V. Belaga,[12] A. Bellingeri-Laurikainen,[40] R. Bellwied,[48] F. Benedosso,[28] R.R. Betts,[9] S. Bhardwaj,[35] A. Bhasin,[19] A.K. Bhati,[30] H. Bichsel,[47] J. Bielcik,[50] J. Bielcikova,[50] L.C. Bland,[3] S-L. Blyth,[22] M. Bombara,[2] B.E. Bonner,[36] M. Botje,[28]

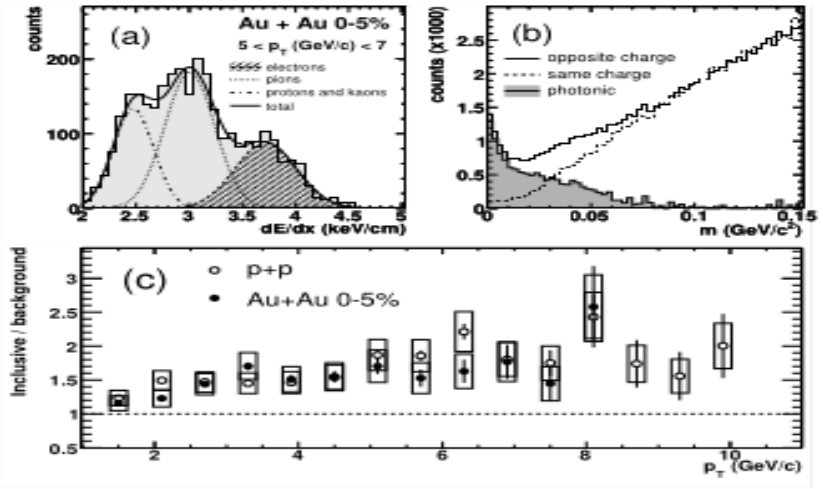


FIG. 1: (a) dE/dx projections for $5 < p_T(\mathrm{GeV}/c) < 7$ in central Au+Au events after EMC and SMD cuts. The lines are Gaussian fits for $p + K$, π, and electron yields. (b) Invariant e^+e^- mass spectrum. (c) Ratio of inclusive and background electron yield vs. p_T for $p+p$ and Au+Au collisions. Vertical bars are statistical errors, boxes are systematic uncertainties.

Semileptonic decays: inclusive electrons (83+% of ECAL modules will be ready)

Transverse momentum and centrality dependence of high-p_T non-photonic electron suppression in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV

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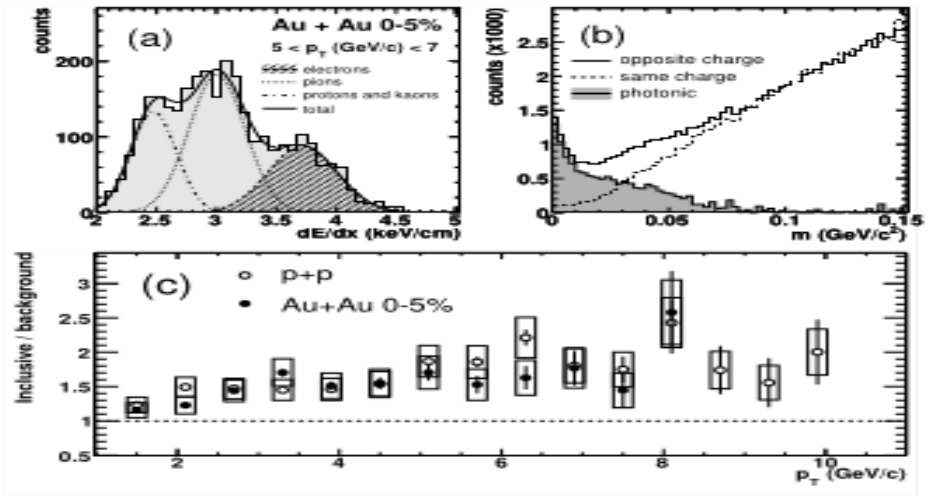

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Erratum: Transverse momentum and centrality dependence of high-p_T non-photonic electron suppression in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV
[Phys. Rev. Lett. 98,192301 (2007)]

B.I. Abelev, M.M. Aggarwal, Z. Ahammed, B.D. Anderson, D. Arkhipkin, G.S. Averichev, Y. Bai, J. Balewski, O. Barannikova, L.S. Barnby, J. Baudot, S. Baumgart, V.V. Belaga, A. Bellingeri-Laurikainen, R. Bellwied, F. Benedosso, R.R. Betts, S. Bhardwaj, A. Bhasin, A.K. Bhati, H. Bichsel, J. Bielcik, J. Bielcikova, L.C. Bland,

Erratum (2011)

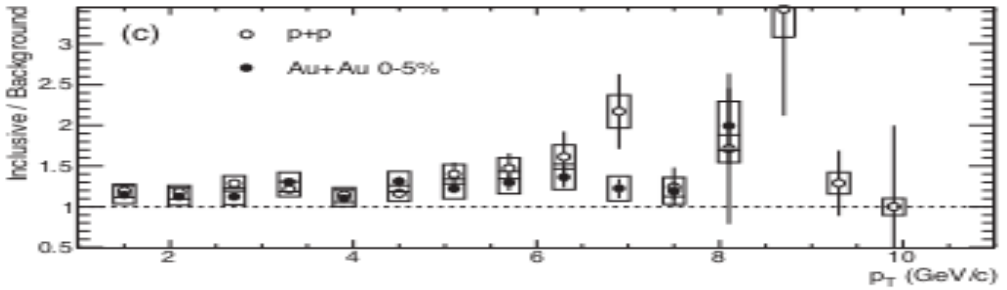


FIG. 1: (c) Ratio of inclusive and background electron yield vs. p_T for $p+p$ and Au+Au collisions. Vertical bars are statistical errors, boxes are systematic uncertainties.

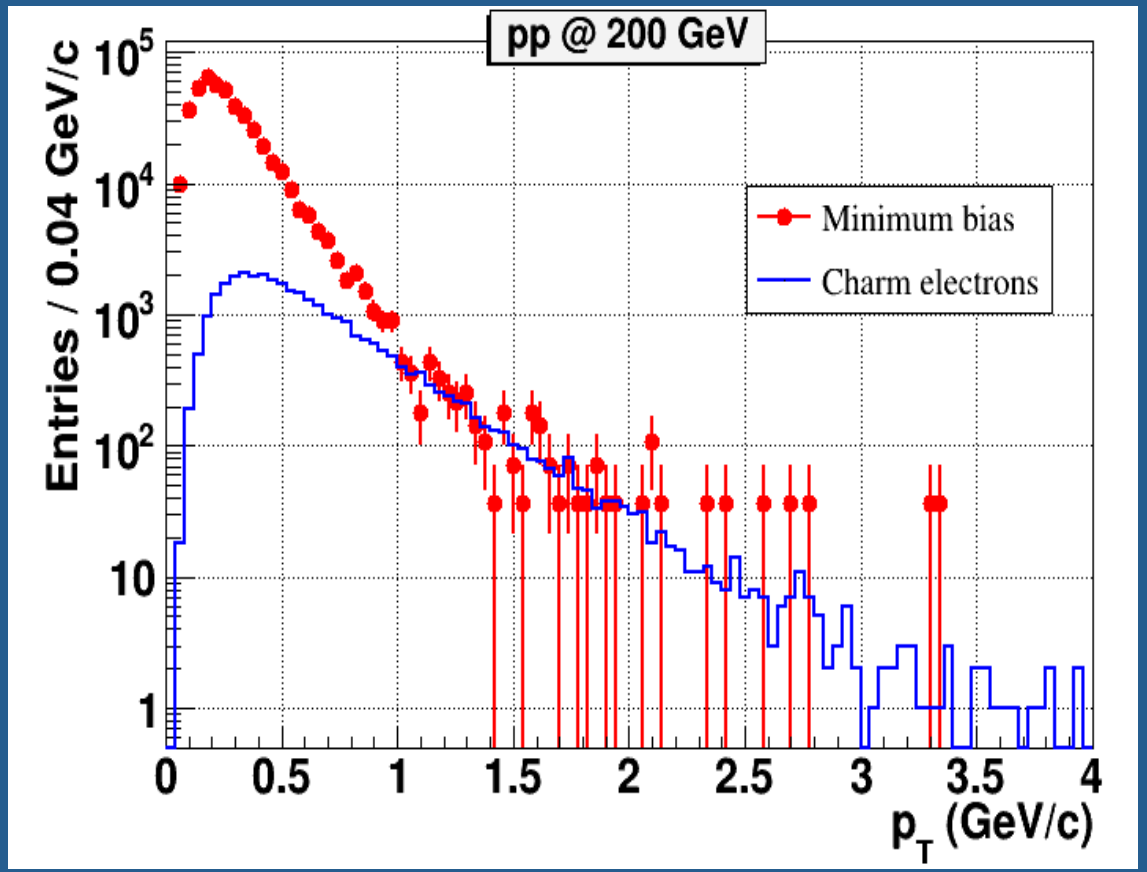
Semileptonic decays: inclusive electrons

1. Cross-sections from Pythia8

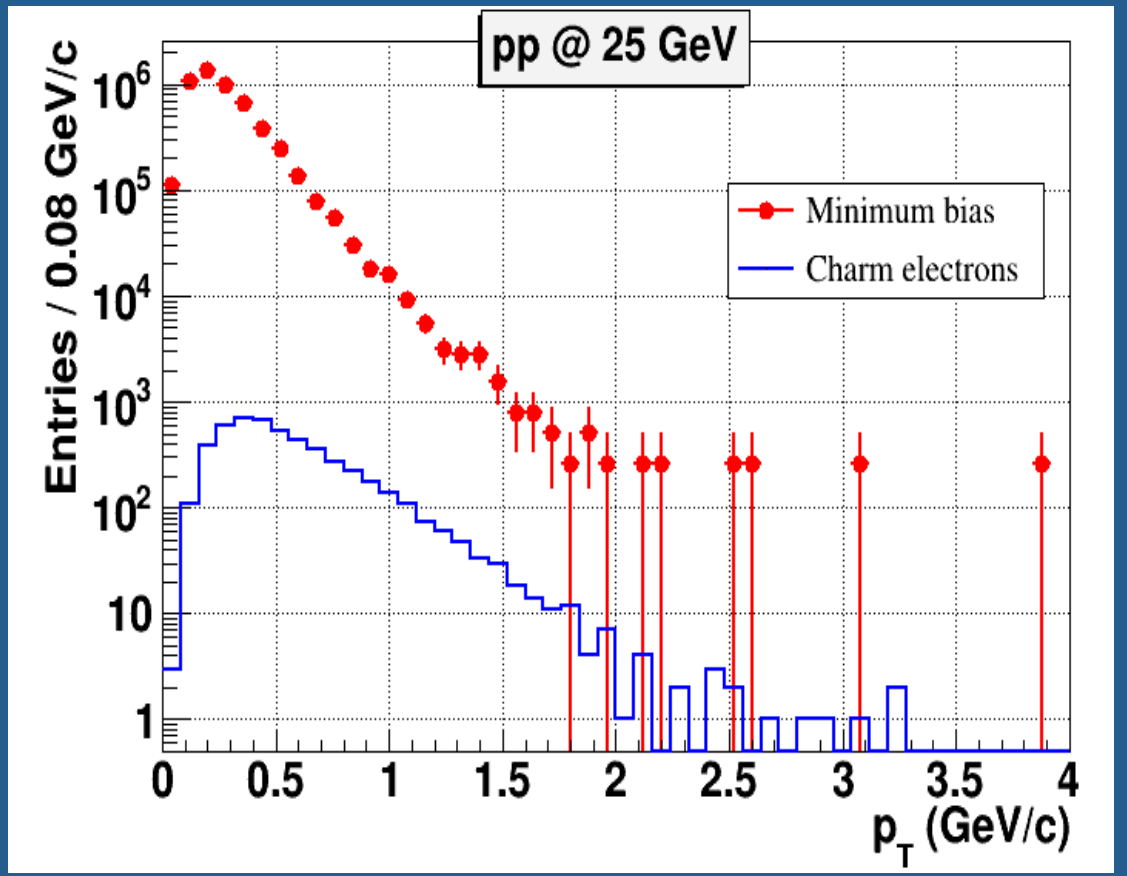
- pp @ 200 GeV:
- minimum bias 28.485 mb, $D \rightarrow e\pm$ $7.833*10^{-2}$ mb
- $L = 100\ nb^{-1}$: $2.8*10^{+9}$ min. bias and $7.8*10^{+6}$ D electrons

1. pp @ 25 GeV:
2. Minimum bias 23.921 mb, $D \rightarrow e\pm$ $4.591*10^{-4}$ mb
3. $L = 100\ nb^{-1}$: $2.4*10^{+9}$ min. bias and $4.6*10^{+4}$ D electrons

Semileptonic decays: inclusive electrons



10^5 D-mesons



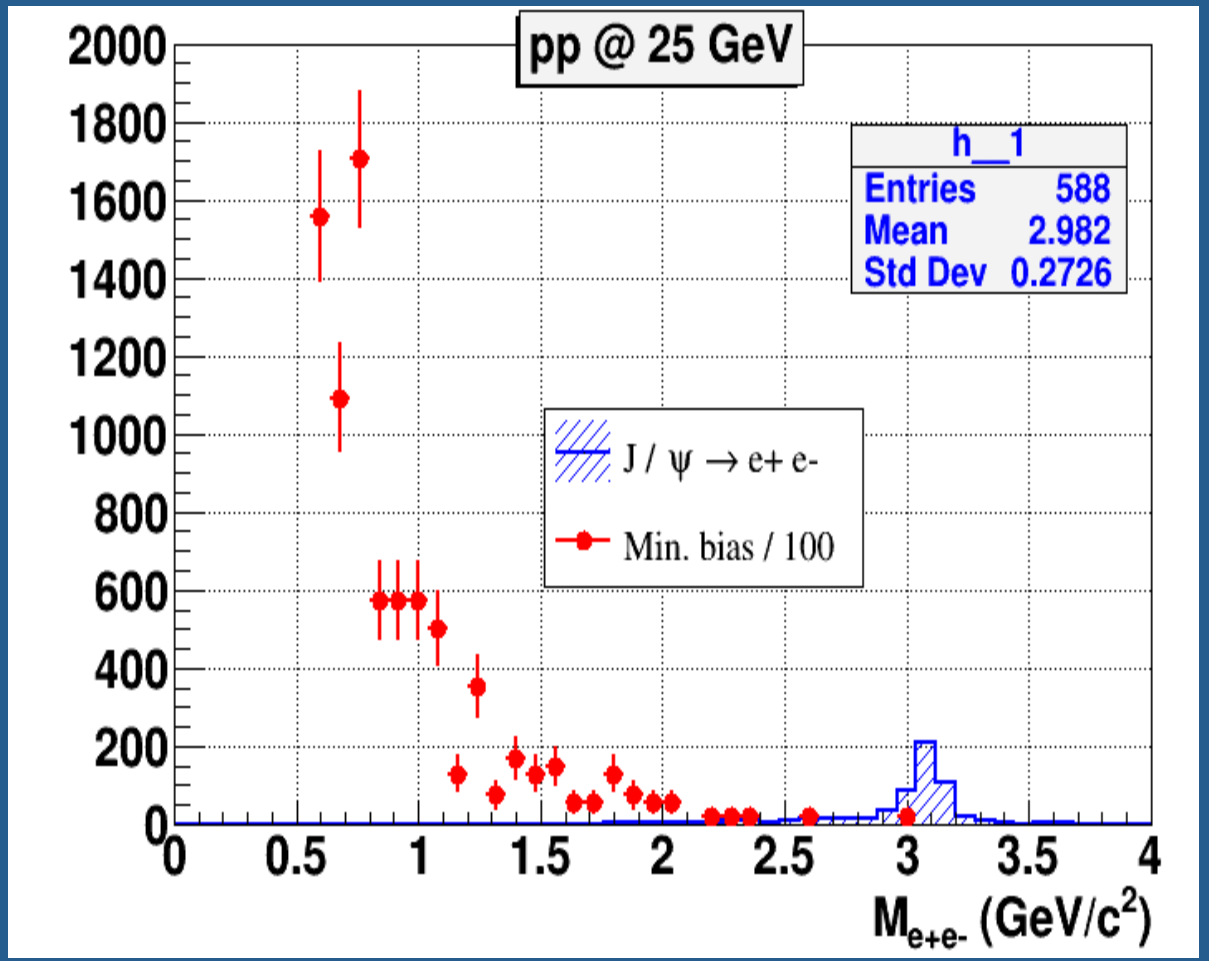
10^4 D-mesons

Hidden charm: J/ψ → e+e-

1. Cross-sections from Pythia8

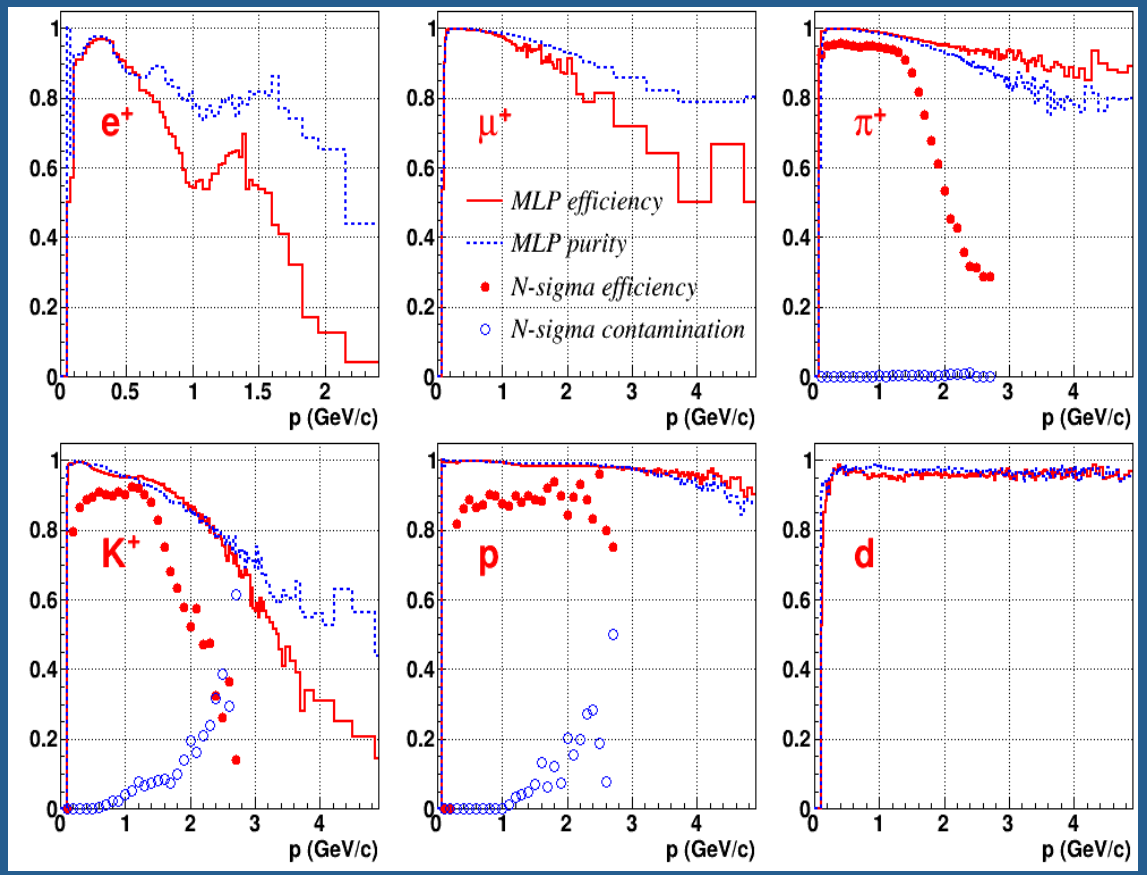
pp @ 25 GeV:
Minimum bias 23.921 mb, J/ψ → e+-
$6.458*10^{-6}$ mb
L = 155 nb^{-1} : $3.7*10^{+9}$ min. bias and
$1.0*10^{+3}$ J/ψ electrons

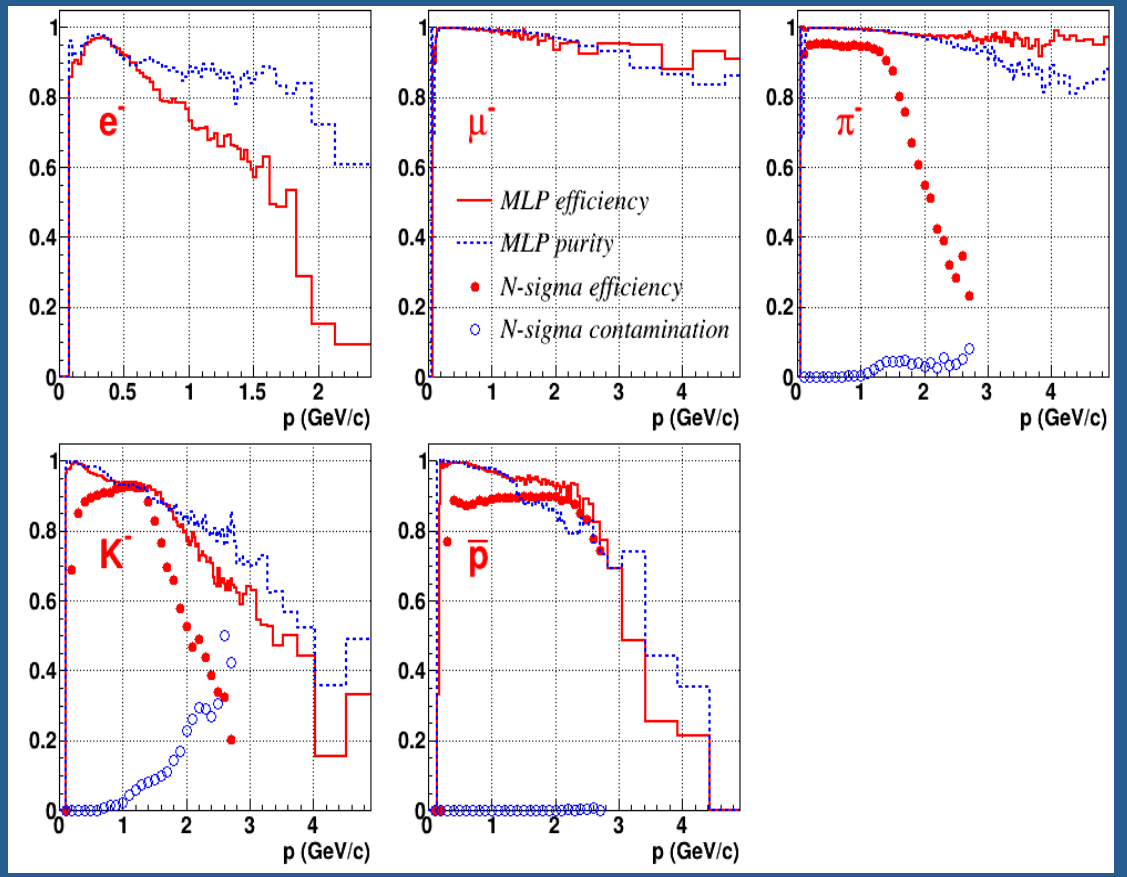
pp @ 11 GeV
J/ → e+- $0.271*10^{-6}$ mb



Particle identification with TMVA

I. Rufanov





Outlook

- The MPD experiment can potentially contribute to charm studies in heavy-ion collisions
- Further studies of the ITS performance and design optimization for open charm
- Feasibility of open charm semileptonic decay measurement should be demonstrated
- Feasibility of J/ψ to e+e- should be studied in more detail

Semileptonic decays: inclusive electrons - TMVA

p+p @ 25 GeV Pythia8 (Equivalent statistics ~500M events)